PERFORMANCE EVALUATION AND COMPARISON OF MIXED MODE FORCED CONVECTION SOLAR TUNNEL DRYER AND PYRAMID DRYER FOR SPINACH LEAVES

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ABSTRACT

A forced convection mixed mode tunnel and pyramid type solar dryers has been fabricated for drying of leafy vegetable such as spinach leaves. The performance of the fabricated driers is evaluated by carrying drying experiments at Miraj, District Sangli. Solar drying of spinach leaves is carried at different air velocities. Initially 2.28 kg of fresh spinach leaves (Initial moisture content of spinach is 90.7% w.b) are dried in both the dryers at air velocity 0.4m/s, 0.5m/s, 0.6m/s and 0.7m/s and performance of the dryer is compared. It is observed that 0.5 m/s air velocity is optimum for drying of spinach in tunnel type dryer while 0.6 m/s for pyramid type dryer. The temperature of the drying chamber of tunnel and pyramid dryers remains higher than the ambient temperature. For spinach the average system drying efficiency of the tunnel type drier varies from 26.72% to 20.99 % whereas of pyramid type dryer varies from 20.93% to 18.30%. The observed result of the present work shows that the proposed forced convection mixed mode tunnel type solar drier is good for drying spinach.

KEYWORDS: Drying, Spinach, Solar Dryer, Mixed Mode Forced Convection, Tunnel, Pyramid.

1. Introduction:

In India more than 40 different kinds of vegetables belonging to different species, like Solanaceous, Cucurbitaceous, Leguminous, Cruciferous, root crops and leafy vegetables are grown in tropical, subtropical and temperate regions.[1] Few leafy vegetables are seasonal and have maximum yield within a short span, which result cost falls ultimately problem with lesser profit. To overcome such a problem we have to increase the shelf life period of leafy vegetables. To increase shelf life, we have to reduce water content in leafy vegetables and process them so as to increase its market value. Drying is one of the most efficient methods used to preserve food products for longer periods.

The ancient method used to preserve food is natural sun drying. But natural sun drying has many disadvantages such as uncontrolled drying, contamination by birds, insects and dust, climatic adversities etc.

The quality of the product is found to be less and cannot be exported. It also requires more labour and the process is found to be slow.[2] All these disadvantages of natural sun drying can be overcome by using solar drying method. Solar drying is a continuous process where moisture content, product temperature and weight of product changes simultaneously along with the solar insolation and the surrounding temperature. The drying rate is affected by weather conditions such as: temperature, relative humidity, available solar insolation, wind velocity, moisture content in the product and duration of the drying period.[3]

2. Material and Methods:

2.1 Development of Mixed mode forced convection tunnel type solar dryer.

The Mixed mode forced convection tunnel type solar dryer consists solar flat plate collector, drying chamber and a small fan to provide the required air flow over the product to be dried. These are connected with each other as shown in Fig.1. The solar flat collector is placed in such a way that the maximum solar radiations are collected on it. Both the collector and the drying chamber (100 mm x 1000 x 580 mm) are covered with UV-protected glass. Copper sheet (1200mm x 500mm x 3mm) is used as collector plate. Black paint is used as an absorber in the collector and inner surface of the drying chamber. The products to be dried are placed in a thin layer on a perforated tray in the tunnel drier. Locally available cheap glass wool and heatlon sheets are used as insulation material to reduce heat loss from bottom and sides of the collector and drying chamber. The hot air coming from collector passes over the drying leafy vegetables absorbs moisture from the leafy vegetables and finally this moist air is released in atmosphere through valve.

2.2 Development of Mixed mode forced convection Pyramid type solar dryer:

The Mixed mode forced convection tunnel type solar dryer consists solar flat plate collector, drying chamber and a small fan to provide the required air flow over the product to be dried. These are connected with each other as shown in Fig.1. The solar flat collector is placed in such a way that the maximum solar radiations are collected on it. Both the collector and the drying chamber (100 mm x 1000 x 250 mm) are covered with UV-protected glass. Copper sheet (1200 mm x 500 mm x 3 mm) is used as collector plate. Black paint is used as an absorber in the collector and inner surface of the drying chamber. In this dryer two perforated trays are placed one above other. The products to be dried are placed in a thin layer on a perforated tray. Locally available cheap glass wool and heatlon sheets are used as insulation material to reduce heat loss from bottom and sides of the collector and drying chamber. The hot air coming from collector passes over the drying leafy vegetables, absorbs moisture from the leafy vegetables and finally this moist air is released in atmosphere through valve.

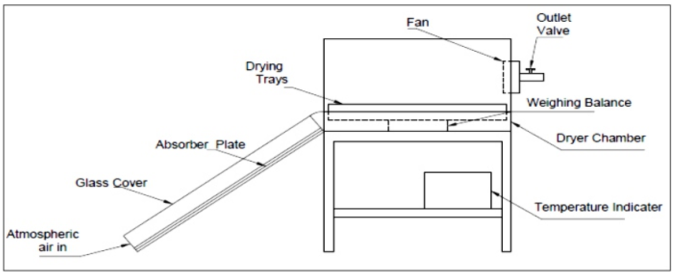


Figure: 1 Experimental Test Setup of Solar Tunnel Dryer

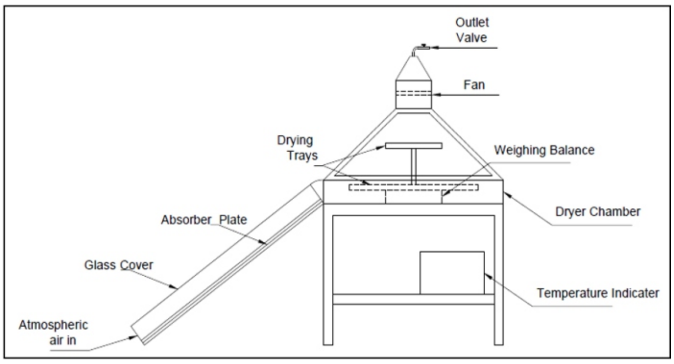


Figure:2 Experimental Test Setup of Solar Pyramid Dryer

3. Instrumentation:

3.1 Solar radiations: The Solar Power meter (TENMAES ELECTRONICS CO.LTD ,

Range: 0-2000 W/m^2, accuracy: Typically + -10W/m^2) is used to measure the solar radiations falling on collector.

3.2 Temperature:

The temperature variations at various points of collector, drying chamber and drying trays is the crucial part of the experimentation. The temperatures are measured by TP01/ Compensating cable K-type thermocouples.

3.3 Air velocity:

Measurement of air velocity and air flow rate during entire experimentation is carried out by using anemometer (HTC Instruments, Range: 0.40 ~ 45.0 m/s , accuracy: + 2% +0.1m/s)

3.4 Measurement of weight:
Weight measurement of leafy vegetables at specific interval of time is most important parameter of this dissertation work. The weight measurement is carried out by electronic weighing balance (United scale agency, Range: 0 to 20 kg).

4. Experimental Procedure:
Experimentation is carried out on spinach and coriander leaves. The initial moisture content of spinach and coriander is measured by oven drying at a temperature of 105ºC for 24 hours at Nikhil Analytical and Research Pvt.Ltd.sangli, Maharashtra. First spinach leaves are uniformly spread (Layer thickness 2.5 cm approximately) in trays and are kept inside the chamber for solar drying. In the newly developed solar driers, air is sucked into the drying chamber from collector with the help of small electrical fans. Due to the solar radiation falling on the collector, the collector gets heated up and transfers heat to the air flowing through the collector. This hot air enters the drying chamber where leafy vegetable is loaded in trays. The moving hot air evaporates the water content (moisture) of the vegetable under the basic mechanism of removal of moisture from the surface of the product to the surrounding followed by the removal of moisture from inside the product to the surface. The readings are taken on hourly basis from 10.00 am to 5.00 pm until leafy vegetable attained equilibrium moisture content. The regulator valve at outlet of drying chamber is adjusted and the air velocity flow rate is kept at 0.4m/s, 0.5m/s 0.6 m/s and 0.7m/s. The entire experiment is repeated to study the performance of leafy vegetable at different air velocity flow rates.

5. Data Analysis:
5.1 Moisture Determination:
Samples of the leafy vegetables of weight (W_o, kg) were dried in the moisture balance at 102 to 105^{0}C until the weight (W_d kg) of the dried sample become stable.

a) Dry Basis:
The moisture content on dry basis (Md_o) of the leafy vegetables is expressed as

$$Md_o = \frac{W_o - W_d}{W_d} \times 100\ \% \tag{1}$$

The instantaneous moisture content of the leafy vegetables on dry basis (Md_i) at any time (t_i) during the drying process is determined by following equation:

$$Md_i = \frac{W_i - W_d}{W_d} \times 100\ \% \tag{2}$$

Where, W_i is the weight of the leafy vegetables at time t_i in kg or gm.

b) Wet Basis:
The initial moisture content on wet basis (Mw_o) of the leafy vegetables is expressed

$$Mwo = \frac{W_o - W_d}{W_o} \times 100\ \% \tag{3}$$

For the determination of the instantaneous moisture content on wet basis (Mw_i) of the leafy vegetables at any time (t_i) during the drying process, the following equation can be used

$$Mw_i = \frac{W_i - W_d}{W_o} \times 100\ \% \tag{4}$$

Where, W_i is the weight of the leafy vegetables at time t_i in kg or gm

The determination weight of the leafy vegetables was done by weighing the drying tray with its load at any time in the drying process.

5.2 Drying Rate:
The instantaneous drying rate DRd_i on dry basis is determined by using following equation:

$$DR_i = \frac{\Delta W_i}{T_d} \times 100\ \% \tag{5}$$

Where, Δ Wi is the difference of weight between when two successive measurements of a drying material (leafy vegetables) is made.

5.3 System drying Efficiency (η_d):
This parameter is defined as the ratio of the energy required to evaporate the moisture to the energy supplied to the dryer. For solar calculations the heat supplied to the dryer is the insolation upon the collector.

The system drying efficiency for drying of spinach is calculated from the Equation.

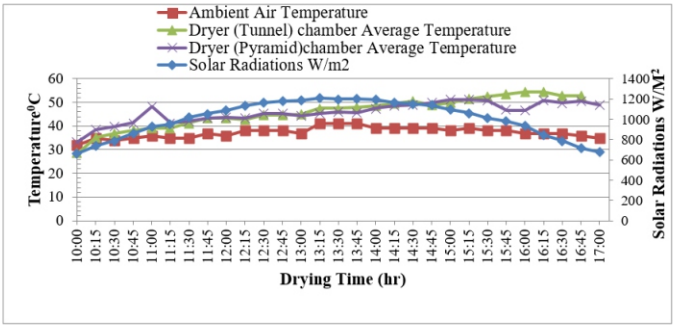
$$\eta_d = \frac{m_w \times H_L}{A_C \times I_i} \times 100 \tag{6}$$

Where, m_w = Amount of moisture evaporated or removed (kg).

($m_w = W_{i-1} - W_i$ where W_{i-1} and W_i are weight when two successive measurements of a spinach is made.)

H_L = Latent heat of vaporization of water, 2320 (kJ/kg).
A_c = Area of the collector (m^2).
I_i = Instantaneous solar insolation upon collector.

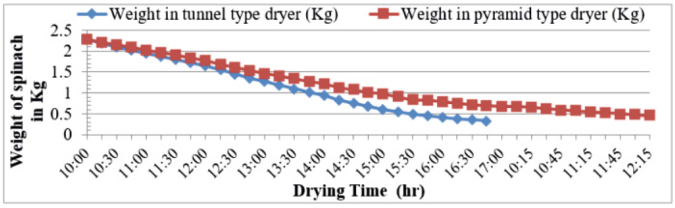
6. Result And Discussion:
6.1 Variation of ambient air temperature, Temperature of air inside the drying chamber and solar radiations with time.



Graph No: 6.1 Variation of ambient air temperature, Temperature of air inside the drying chamber and solar radiations with time, initial weight of spinach 2.28 kg and air velocity 0.5 m/s.

Graph 6.1 shows that the average ambient temperature ranged between 32- 41°C and at 1:15 pm to 1:45 it was maximum i.e 41°C. The average temperature of drying air inside the drying chamber goes on increasing with time and solar radiations. For tunnel type dryer average temperature of air inside drying chamber ranged between 28.5 to 54.5 °C and for pyramid type dryer it was 33.25 to 51.25°C.

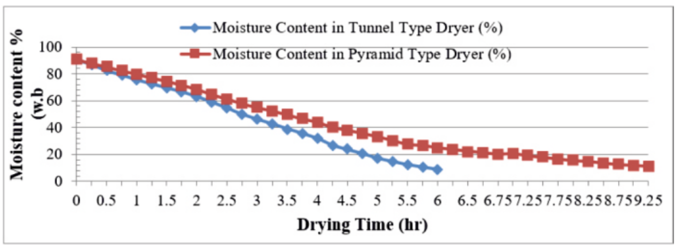
6.2 Drying Time Vs Weight of Spinach:



Graph No: 6.2 Drying Time Vs Weight of Spinach, initial weight 2.28 kg and air velocity 0.5 m/s.

Graph 6.2 shows the weight of spinach decreases with increase in the drying time. The tunnel type dryer took 6 hours to reduce weight from 2.28 kg to 0.419 kg at which moisture content could be 9.077 % (wb). Pyramid type dryer took 9.25 hours to reduce weight from 2.28 kg to 0.462 kg at which moisture content could be 10.96 % (wb). 6.3 Drying Time Vs Moisture Content:

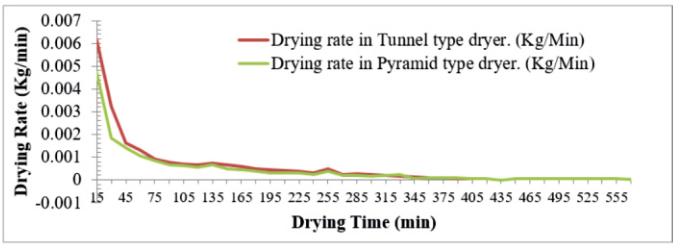
6.3 Drying Time Vs Moisture Content:



Graph No:6.3 Variations of the moisture content of Spinach using tunnel and pyramid type solar dryer, initial weight 2.28 kg and air velocity 0.5 m/s.

Graph 6.3 shows at 0.5 meter per second air velocity, tunnel type dryer took 6 hour to reduce moisture from 90.7% (wb) to 9.077 % (wb) while pyramid type dryer took 9.25 hours to reach 10.96 % (wb) moisture content.

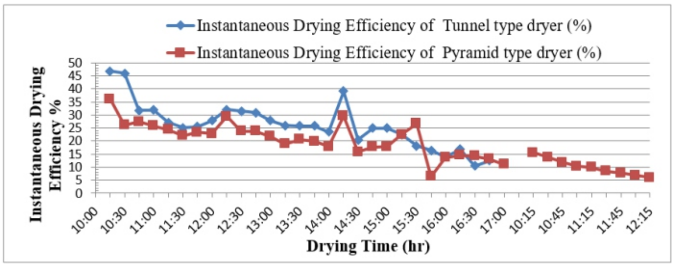
6.4.4 Drying Time Vs Drying Rate:



GraphNo:6.4 Variation of drying rate with time for Spinach in tunnel and pyramid type dryer, initial weight 2.28 kg and air velocity 0.5 m/s.

During the first 15 minute the drying rate in tunnel type dryer was 0.00613 kg per min while in pyramid type dryer it was 0.004733 kg per minute. During night it is observed that the product absorbs some moisture from surrounding even in polythene bag and hence weight increases and drying rate becomes negative.

6.4.5. Drying Time Vs Instantaneous System Drying Efficiency



Graph No: 6.5 Instantaneous System Drying Efficiency Verses Drying Time for spinach. Initial weight 2.28 kg and air velocity 0.5 m/s.

Graph no 6.5 shows the system drying efficiencies of the tunnel and pyramid type dryers for the first day of the first measurement were found to be 46.83% and 36.14 %, respectively. Thermal efficiency of tunnel type dryer varies between 46.83 % to 12.54 % and of pyramid type dryer 36.14 % to 5.96% during the entire drying period.

7. Conclusion:

The mixed mode forced convection tunnel type solar dryer and pyramid type solar dryer are evaluated and their different performance characteristics are carefully studied in this work. Air velocity less than 0.4 m/s second is not sufficient to drive out moisture from the enclosure. Hence this velocity is the lower threshold limit. Tunnel type solar dryer gives maximum drying efficiency at velocity of 0.5 m/s i.e. 26.72%. So for given weather conditions 0.5 m/s air velocity is optimum air velocity for spinach drying in tunnel type dryer and 0.6 m/s for pyramid type solar dryer.

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